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Abstract: The political transformation of the Central Asian region has induced the implosion of the interconnected physical hydraulic infrastructure and its institutional management systems. Land-locked Central Asian countries with their climatic conditions and transboundary water resources have been striving to meet their food security, to increase the agricultural production, to sustain the energy sectors and to protect the environment. The existing water reservoirs are strategic infrastructures for irrigation and hydropower generation. The upstream countries (Tajikistan and Kyrgyzstan) favor the reservoirs operation for energy supply while the downstream countries (Uzbekistan, Turkmenistan and Kazakhstan) push on the irrigation use. This paper overviews the current challenges and perspectives (technical, institutional and legal regulations) of man-made water reservoirs in Central Asia with special focus on Uzbekistan.

Keywords: transboundary waters, dam management, water reservoirs, irrigation, hydropower, sedimentation, water policy

1. Introduction

Transboundary water management and governance has been a hot topic in Central Asia for the last two decades after the disintegration of the former Soviet Union [5; 7; 21; 26]. In fact the United Nations Development Programme (UNDP) [24] reports that the Central Asian region loses $1.7 billion per year i.e. three per cent of the region's GDP (Gross Domestic Product) from the poor water management that lowers the agricultural yields. Moreover some 22 million people depend directly or

indirectly on irrigated agriculture in these countries [29]. The sustainability of irrigated agriculture is one of the main platforms for food security, employment, livelihoods and environment protection in Central Asia [18].

The Central Asia countries (Tajikistan, Kyrgyzstan, Kazakhstan, Turkmenistan and Uzbekistan) have inherited an interconnected and sophisticated hydraulic infrastructure from the Soviet era. As described by Libert et al [8] and Rakhmatullaev et al [17] the hydraulic mission of the soviet administration was set up from an engineering perspective based on the construction of large dams and water reservoirs in the mountain areas, upstream countries (Tajikistan and Kyrgyzstan) due to the attractiveness of natural conditions, i.e., more water accumulation per unit area in comparison to plains (lowland) conditions, downstream countries (Uzbekistan, Kazakhstan and Turkmenistan). On the other hand lowlands were suitable for practicing irrigated agriculture and growing water intensive agricultural crops (cotton, rice and wheat).

The recent pivotal area of discussions is hydropower versus irrigation mode for the operation of the reservoirs and dams in Central Asia e.g., the Toktogul reservoir in Kyrgyzstan (Syr Darya River Basin) and the construction of the Rogun hydropower station in Tajikistan (Amu Darya River Basin).

In fact various paramount technical, operational and biophysical aspects impact the sustainable operation and management of dams and water reservoirs in the region which do not have transboundary issues such as sedimentation, improper operation and over-use of hydraulic infrastructures against the designed operational regimes, lack of national legal and institutional frameworks on dam safety. These acute issues are to be seriously addressed at national and regional levels.

Some experts argue that the region will face global warming effects which will have impact on the formation of water resources in the mountain systems of the Tian Shan and Pamir-Alay due to the decrease of the ice cover [4; 10].

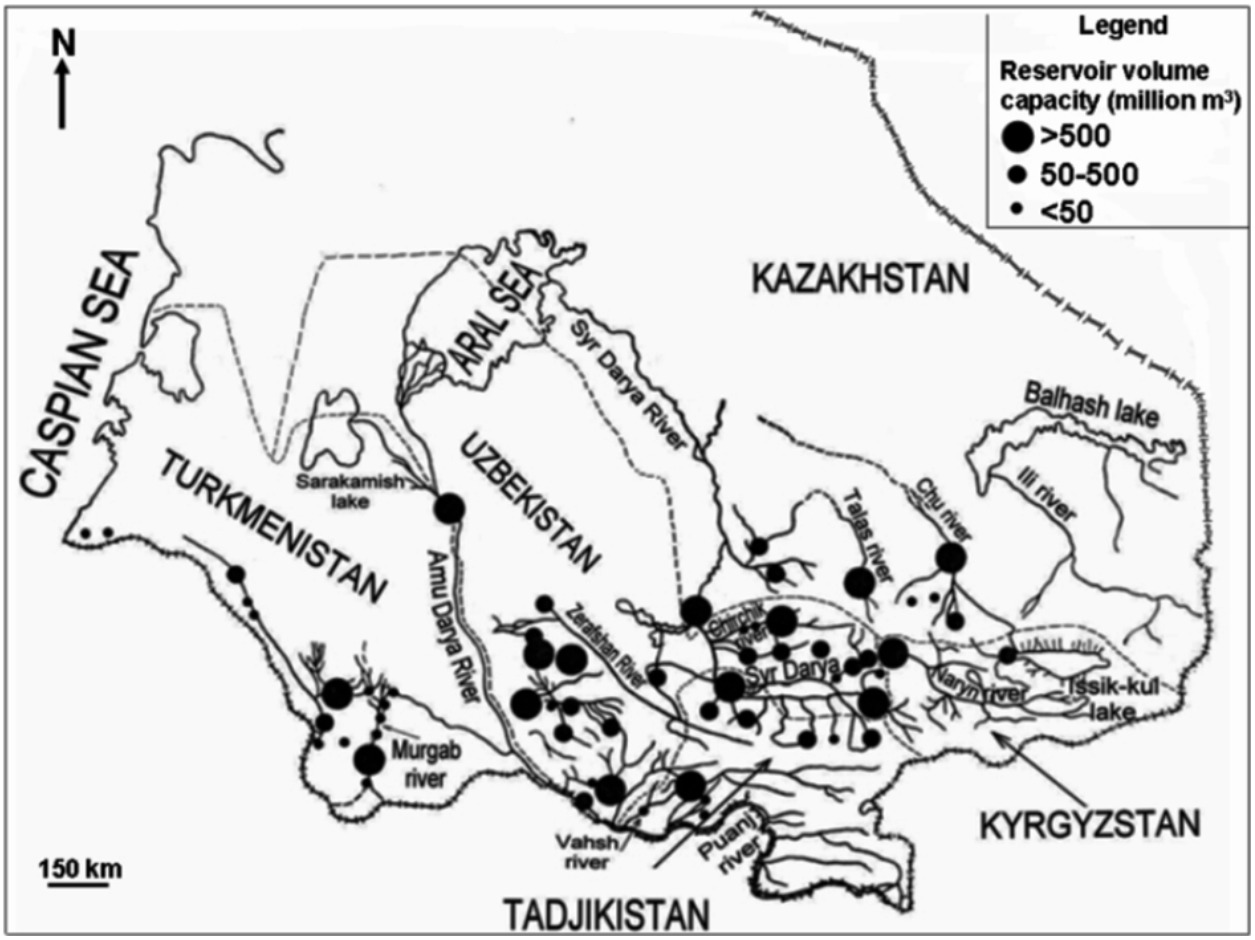
The World Commission on Dams (WCD) [27] outlines that large hydraulic infrastructures such as dams and its associated water reservoirs have played an important role in the regional development in many parts of the world. In the Central Asian region, man-made water reservoirs play a particularly paramount role where natural precipitation is erratic or seasonal with uneven spatial and temporal water resources distribution [28]. In fact water reservoirs store water during wet periods to make it available during dry periods for regulating floods, generating hydropower, and irrigation. Thus it is important to discuss technical, management aspects of dams and its associated water reservoirs.

The primary objective of this paper is to overview the situation on dams and water reservoirs in terms of technical, legal and institutional aspects in the new geopolitical realities in the region with a special focus on the Uzbekistan experience with a large hydraulic infrastructure safety framework. Perspectives and concrete recommendations are given for improving the regional dialogue on sustainable hydraulic infrastructure operation and management.

2. Water reservoirs

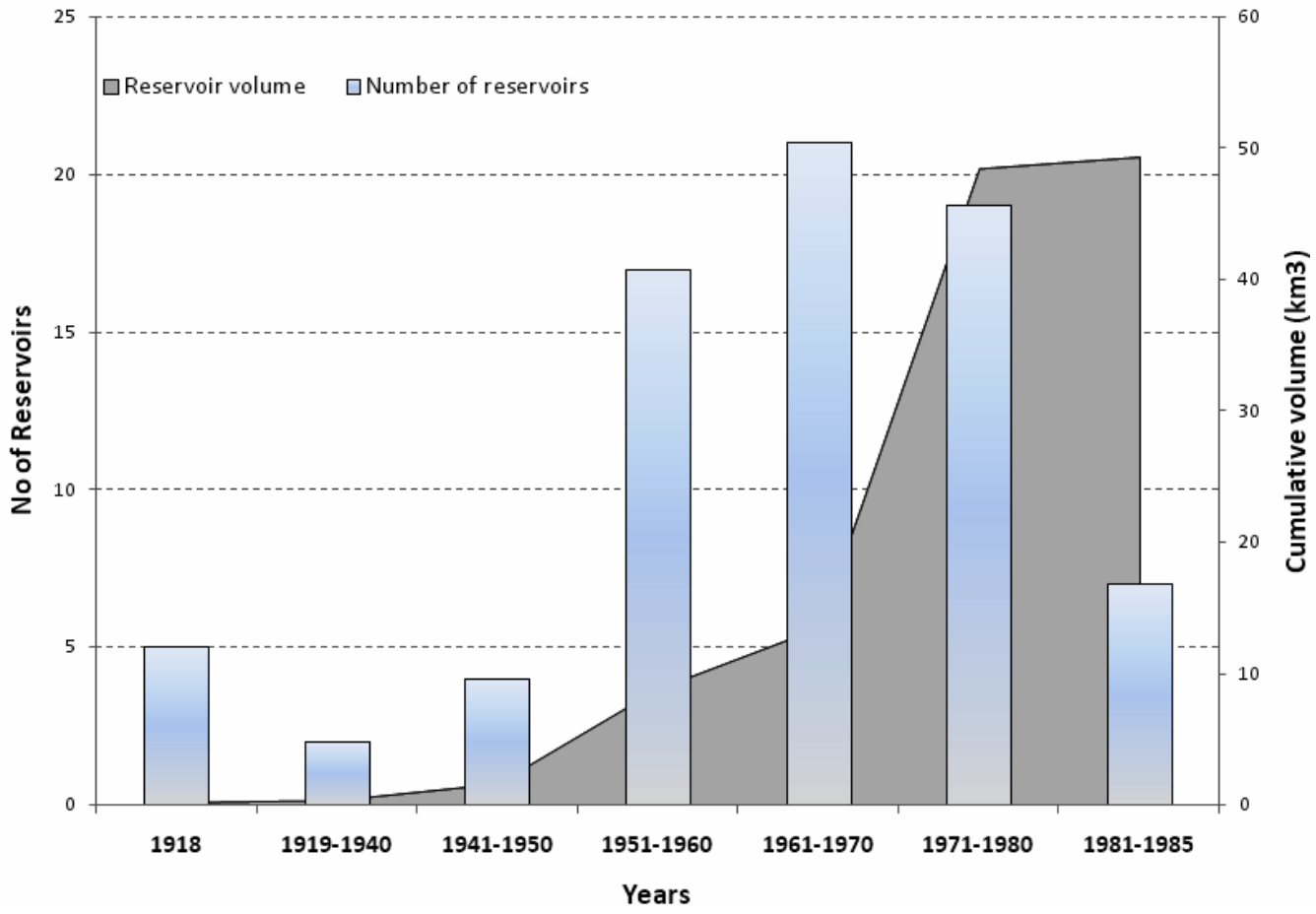
The first water reservoirs in the Central Asian region were constructed as early as in the X-XI centuries [1; 12]. For the regulation of the region's rivers hundreds of man-made water reservoirs were constructed to mitigate natural shortage of water resources (Figure 1).

Figure 1. Schematic location of main water reservoirs and their volume capacities in Central Asia (excluding reservoirs in central and northern region of Kazakhstan).



The era of massive water reservoir construction was documented in the late 1900s. From 1950 to 1980) more than 60 large reservoirs have been constructed in the region (Figure 2). The gross reservoir volume has increased by 50 folds from 0.17 to 49.3km^3 as a part of unprecedented increase of water storage capacities around the globe. Most of the dams and water reservoirs in the region have been constructed for irrigation purposes with a few for hydropower generation. As a result over a period of 90 years (1913-2003) the areas under irrigation have increased by 3 fold in Central Asia, e.g. from 4.51 million ha in 1960 to 6.92 million ha in 1980 and to 7.85 million ha in 2000 [13; 25]. The peak of dam construction is dated to the soviet period when its policy was aiming at expanding irrigated lands for the mass production of cotton.

Figure 2.: Number of reservoirs and cumulative volume in Central Asia for the last century.



At the moment there are more than 290 water reservoirs in Central Asia with a total volume capacity over 163 km^3 that regulate more than 50% of the monthly regions river flow and the area occupied by reservoirs constitutes roughly 6% of the Central Asian countries irrigated areas (Table 1) [2; 20]. For example, on average about 30% of irrigation water is delivered from reservoirs in the region, ranging as high as 54% in Turkmenistan and as low as 13% in Kyrgyzstan.

Table 1: Distribution of water reservoirs by total volume and numbers in Central Asia countries (Food and Agriculture Organization of United Nations, 2009)

Country	**Total reservoir volume capacity (km^3)**	**Number of reservoirs**	**Irrigation water from reservoirs (%)**
Kazakhstan*	88.8	180*	32
Kyrgyzstan	23.5	18	13
Tajikistan	29	19	28
Turkmenistan	2.89	18	54
Uzbekistan	19	55	24
Total in CA	**163.19**	**290**	**Average 30**

*The number of reservoirs represents for whole Kazakhstan.

There are 45 large-scale hydropower stations with a gross capacity of 36.7 GWh/year on large water reservoirs in the Central Asian region [15]. However the hydropower constitutes only 11% in Uzbekistan whereas more than 90% is produced in Tajikistan [7]. Kyrgyzstan and Tajikistan have about 78% of the total hydropower potential of the region but utilize only 10% of its potential.

Reservoirs in Uzbekistan

The total number of man-made water reservoirs in Uzbekistan is 55 (Table 2) [17; 23].

Table 2. Distribution of water reservoirs in Uzbekistan by administrative boundaries (United Nations Development Program, 2007)

Province	**Number**	**Useful Volume Capacity (km^3)**	**Province**	**Number**	**Useful Volume Capacity (km^3)**
Amu Darya River Basin			*Syr Darya River Basin*		
Khorezm	1	4.5	Andijan	3	1.7
Kashkadarya	14	2.3	Tashkent	5	1.9
Samarkand	7	1.1	Fergana	4	0.25
Surkhandarya	4	0.9	Namangan	7	0.23
Navoi	2	0.8	Jizzak	4	0.18
Bukhara	2	0.4	Syrdarya	2	0.01
Total	**30**	**10.1**		**25**	**4.45**

The total gross volume capacity of all reservoirs is about 19 km^3 and the useful volume capacity is about 14.5 km^3 whereas the total surface area of reservoirs is estimated at *ca*. 1450 km^2 in Uzbekistan. The total reservoir volume capacity is defined as maximum water amount stored, whereas the useful volume capacity is actual available water storage. The arithmetic difference makes the dead storage of a reservoir. In other words the dead volume storage in a reservoir is determined as the storage volume between the stream bed and the lowest elevation from which water can be withdrawn by gravity (Mahmood, 1987). The difference observed between total capacity and useful capacity is an indicator of the efficiency of the dam and water management. The 4.5 km^3 difference represents a loss percentage of 26% due to topographic peculiarities, i.e., most of water reservoirs are constructed in lowlands in Uzbekistan.

The nine major reservoirs constitute about 86% (16.8 km^3) of the total reservoir volume capacity and about 94% (1362 km^2) of the total surface area (Table 3). Almost 90% of all dams are used for irrigation purposes and only two for hydropower (Andijan and Charvak) [16]. About 75% of dams were constructed in the 30-years period from 1961 to 1990 with 93% of a total reservoir capacity known as the “soviet period”. At the moment, 3 water reservoirs are being constructed in the Namangan, Jizzak and Samarkand provinces of Uzbekistan for increasing the water storage capacities.

All dams and their associated water reservoirs are aging and numerous biophysical, technical and management aspects need to be addressed for the sustainable management of water resources and hydraulic infrastructures. These aspects should be addressed at the national levels and in particular for hydraulic structures which have transboundary importance.

2. Threats to water reservoirs

Almost all hydraulic infrastructures in particular dams and their associated water reservoirs are aging (constructed during the 1930-40 period) [9]. Thus there is some urgency for the safe operation on such structures in order to avoid devastating emergency situations in the event of technical

operational failures or natural phenomena such as earthquakes. For example, Civil engineering, in term of life cycle and survey, but also water practices and legal aspects are linked and supposed to plan management of the structure and resources at different steps and scale. This is, actually, a key point discuss at national level and very often problematic at international one (i.e. case of the transboundary rivers).

Reservoir sedimentation

A reduced reservoir volume capacity due to sedimentation triggers operation and maintenance issues coupled with economic feasibility of the project, environmental concerns and social aspects [11; 28]. Sedimentation is a natural geomorphologic process but human interference increases its rates. Sedimentation reduces the main reservoir asset *i.e.* its volume capacity over time due to the feeding rivers [6]. It is reported that an annual average 0.5-1% loss of volume capacities of small and large reservoirs is observed due to sedimentation in the world. Palmieri et al. [14] reports that the loss in volume capacity requires an annual replacement cost of 13 billion US$.

The most recent reports indicate that an average annual reservoir volume loss is estimated at 0.5% in Uzbekistan (Table 3) [16]. As it can be seen the total volume capacities of major reservoirs have decreased by about 20% and its dead storage capacities have decreased by 55%. For example, the dead volume capacities of 7 reservoirs decreased by more than 75%. This is an alarming signal that in the future the sedimentation rates can be unprecedented with several operation and maintenance problems.

Table 3. Loss of reservoir volume (total and dead) of selected major reservoirs in Uzbekistan

Reservoir	**River Basin**	**Total Volume (Mm^3)**	**Silted volume (%)**	**Started to operate (Year)**
Talimarjan	Amu Darya	1525	3.9	1985
Janubiy Surkhan	Surkhan Darya	800	37	1967
Kuyimazar	Amu Darya	310	11.2	1958
Tudakul	Amu Darya	1200	13.7	1983
Andijan	Kara Darya	1900	13.4	1970
Kattakurgan	Zerafshan	900	22.5	1953
Chimkurgan	Kashka Darya	500	22.7	1963
Ruslovoy*	Amu Darya	2340	44.9	1980
Kaparas*	Amu Darya	960	1.9	1983
Average			**19**	

*Tuyamuin is composed of four reservoirs: 1) Ruslovoy - 2.34km^3; 2) Sultansanjar - 2.69km^3; 3) Kaparas - 0.96km^3; 4) Koshbulak - 1.81km^3.

Reservoir sedimentation is an acute issue in Central Asia due to naturally high turbidity of the watercourses. In fact most of the reservoirs have been silted to a great extent. Sedimentation impacts the guaranteed water supply for the different water users (irrigation, industry and hydropower) at the national and regional levels.

For example, the direct loss of reservoir volume capacity is in the form of less hydropower production capacity available for sale, less irrigated land to produce food and a reduced flood routing capacity. Moreover the deterioration of water quality in reservoirs can be a major issue with increasing levels of various contaminants from agriculture, industry, and natural sources whether organic (pesticides, PCBs, PAHs) or inorganic (trace metals) [19]. Dam cavitation and abrasion of conduits, valves, sluice gates and hydropower turbines dramatically impact hydraulic facilities and structures [22]. Moreover social aspects can also be the unattractiveness for tourism and the loss of recreation opportunities.

The common engineering practice advocates for "design for life" approach for dam and reservoir conception. The design for life approach assumes a finite project life which means that future generations should bear all occurring costs and treats [6].

Palmieri et al [14] proposed a new "life cycle management" approach for the sustainable management and use of hydraulic infrastructures. The ultimate goal of this approach is the sustainable use, where the major functions of the dam are maintained, through good management and maintenance. It means that these hydraulic infrastructures should be considered as economic assets and by proper mitigations measures there should be long-term generating benefits to local populations.

Water reservoirs operation guidelines

It is known that all large scale hydraulic infrastructures in particular dams and water reservoirs are designed and constructed according to a design operation regime which safeguards the durability of the operations. However, the real situation is quite different. The weighted decision for the operation of water reservoirs lies in the hand of local government authorities (hokimiyats, i.e., governor) who are responsible for the agricultural production of cotton and wheat. The water management organizations are left with only a technical assistance role for the water supply matters. In most cases, the design operation regime is violated and poses severe circumstances for hydraulic infrastructures. Infrastructure fatigue puts additional pressure on proper management of scare water resources.

Institutional management of water reservoirs

The hydraulic infrastructures in particular dams and water reservoirs are managed, rehabilitated and operated by the Ministry of Agriculture and Water Resources of Uzbekistan. In addition the State Joint Stock Company UzbekEnergo is a responsible authority for the operation and management of hydropower plants in Uzbekistan. For example, about 11.5% of power generation is produced through 29 hydropower plants and two large dams (Charvak and Andijan). There is an overlap of responsibilities of the two state agencies on the management of dams and its associated water reservoir.

Gosvodkhoznadzor is a state inspection agency for the safety of large hydraulic infrastructures in Uzbekistan [3]. There are almost 273 large hydraulic infrastructures (55 water reservoirs, 35 pumping stations, 29 hydropower plants, 60 irrigation main canals, 64 water-intake schemes, 24 main collectors and 7 riverbank protection structures). Gosvodkhoznadzor inspects the safety of large hydraulic infrastructures and sanctions the Ministry of Agriculture and Water Resources of Uzbekistan for

proper actions and mitigation measures. Unfortunately, in most cases the recommendations are in form of suggestions.

3. Institutional and Legal frameworks

The main bottleneck for dam safety monitoring and control is lack of national legal frameworks and appropriate institutions in all Central Asian countries except Uzbekistan [9]. After the dissolution of the former Soviet Union, large hydraulic infrastructures have been left without proper attention from the Central Asian countries. For example, in Kazakhstan, the hydropower plants are managed by semi-private entities and the reservoirs are still operated by government water management authorities. There is always a dispute for the coordinated operation and maintenance of hydropower plant and dam.

In Uzbekistan, the national Law on the safety of hydraulic structures was adopted in 1999. There is an established institutional framework for monitoring of large hydraulic infrastructures namely the State Inspection (Gosvodkhoznadzor) for control and monitoring of technical conditions and safety operations of large-scale hydraulic infrastructures under the Cabinet of Ministries of the Republic of Uzbekistan.

UNECE (United Nations Economic Commission for Europe) is actively participating in the development of regional agreement on cooperation on dam safety in particular the information exchange and notification of other countries in case of accidents with dams [8].

4. Transboundary issues

Uneven spatial and temporal water resources and a Soviet inherited unified hydraulic infrastructure have raised transboundary reservoir management issues over the water resources allocation among the countries in the region such as Kyrgyzstan, Tajikistan, Kazakhstan, Uzbekistan and Turkmenistan. The rivers such as Syr Darya and Amu Darya are already regulated by more than 78% and 94% respectively and attempts for new reservoir projects upstream raises increased concerns of the downstream countries (*e.g.* the Rogun hydropower station in Tajikistan and the Toktogul reservoir in Kyrgyzstan) (Figure 3).

Competition for water resources is prioritized by the downstream countries (Uzbekistan, Turkmenistan and Kazakhstan) for irrigation whereas upstream countries (Tajikistan and Kyrgyzstan) use them mainly for hydropower generation [5; 13]. There has been a serious conflict related to the water resource management of some hydraulic infrastructures like the Toktogul reservoir located in Kyrgyzstan in the recent post-soviet period.

Figure 3. Major transboundary rivers in Central Asia

This water storage infrastructure serves for the needs of the entire Syr Darya River basin. Its main purpose is to regulate and secure the Syr Darya River flow during the growing season (April-September) for irrigation. It was designed to release 8.5 km^3 of water during the growing season and in order to restore the storage only 2.8 km^3 during the non-growing season (October-March).

The surplus of hydropower generation by Toktogul dam in summer was transmitted into the former Central Asian Power System Grid for the usage by downstream countries of Kazakhstan and Uzbekistan. For compensation Kazakhstan supplied fossil fuels and Uzbekistan provided electricity to Kyrgyzstan for electricity needs in winter months.

However the situation has significantly changed due to the end of the former Soviet Union. During 1990 to 2000 summer releases declined to 45 per cent and winter releases increased to 55 per cent of the annual discharges [24].

5. Perspectives

The following key perspectives are addressed in the article for a sustainable management of the water reservoirs and dams.

Mini Hydropower schemes

Small hydropower schemes should be advocated in CA countries for their financial, technical, management and environmental feasibility aspects. These mini hydropower schemes would not significantly alter the hydrological regimes of main transboundary watercourses for different water

uses. These schemes are financially attractive for international donor communities and less environmentally impact-oriented for upstream and downstream riparian ecosystems.

Institutional framework

For a regional cooperation on dams and water reservoirs management in Central Asia, the authors recommend the creation of a regional chapter of the International Commission on Large Dams (ICOLD) which can play as a neutral key regional institution on dam safety. Under the umbrella of the Central Asia ICOLD, national responsible agencies can cooperate and discuss various topicalities. The mandates of such organization could be harmonization of cooperation of the Central Asian states on dam safety, monitoring procedures, information exchange and development of comprehensive database. This can be a first step to create a regional platform for discussion of current issues on management, operation, maintenance of large hydraulic structures.

Legal framework

In order to synchronize the cooperation on dams and its associated water reservoirs management each country should develop its own laws on safety of hydraulic infrastructures. Only Uzbekistan has adopted such a law in 1999. Only after each country has its own law then regional legal framework can be developed.

Mitigation measures

For a regional cooperation on dams and water reservoirs safety, proper technical and management activities should take place at the national level in order to sustainably operate and manage these sophisticated infrastructures. It is time to overlook and assess the present technical conditions of all large infrastructures for each country.

The best practices (mitigation measures) can then be shared and duplicated among other regional countries. For example, in Uzbekistan a new GIS (Geographic Information System) in combination with depth measurement systems are being used for the operative estimation of reservoir sedimentation volumes [16].

As the infrastructure fatigue will be reached in this century, appropriate planning programs should be designed and implemented such as a retirement fund for dam and water reservoir [14]. The retirement fund is intended to accumulate annual contributions made during the life of the dam to pay for any actions required at its retirement. For example, a change of purpose (e.g. recreation, farming, environment creation) from its present irrigation or hydropower generation and in extreme cases dam retirement using partial or complete removal of the dam. However, the partial or full decommissioning of dam would not be economically feasible in the region due to the high financial costs and the existence of a real local expertise. The practical approach is the change of dam or reservoir purpose which still can be attractive to local authorities.

5. Conclusions

Large hydraulic infrastructures play an important role for the Central Asian region development in particular dams and its associated water reservoirs. The main purpose of dams and water reservoirs is hydropower generation, water supply for irrigation and industry. However, these hydraulic structures face numerous problematic issues such as infrastructure fatigue, biophysical issues, operation and maintenance on national levels.

With new geopolitical realms in the region after the collapse of the former Soviet Union and emergence of new independent states regional and transboundary aspects have arisen for cooperative management of water resources and cost sharing of operation and maintenance. In the domain of large hydraulic infrastructures safety transparent legal and institutional frameworks should be developed and adopted reflecting transnational good spirit of cooperation.

A regional platform should be developed such as a branch of the ICOLD which will serve as professional union for the harmonized management and operation of dams and water reservoirs on transboundary watercourses.

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